

# What controls soil carbon storage in forest ecosystems?

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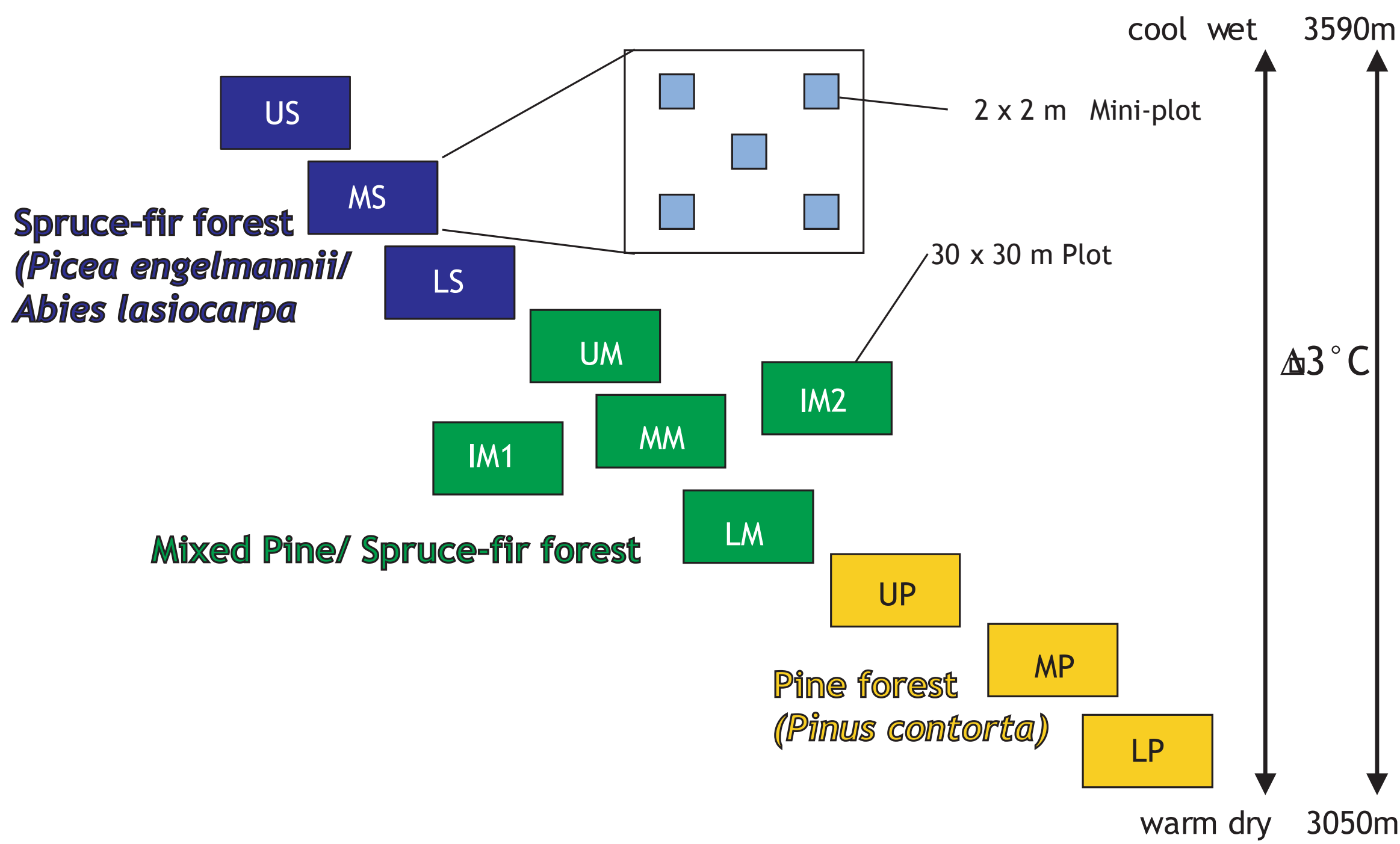
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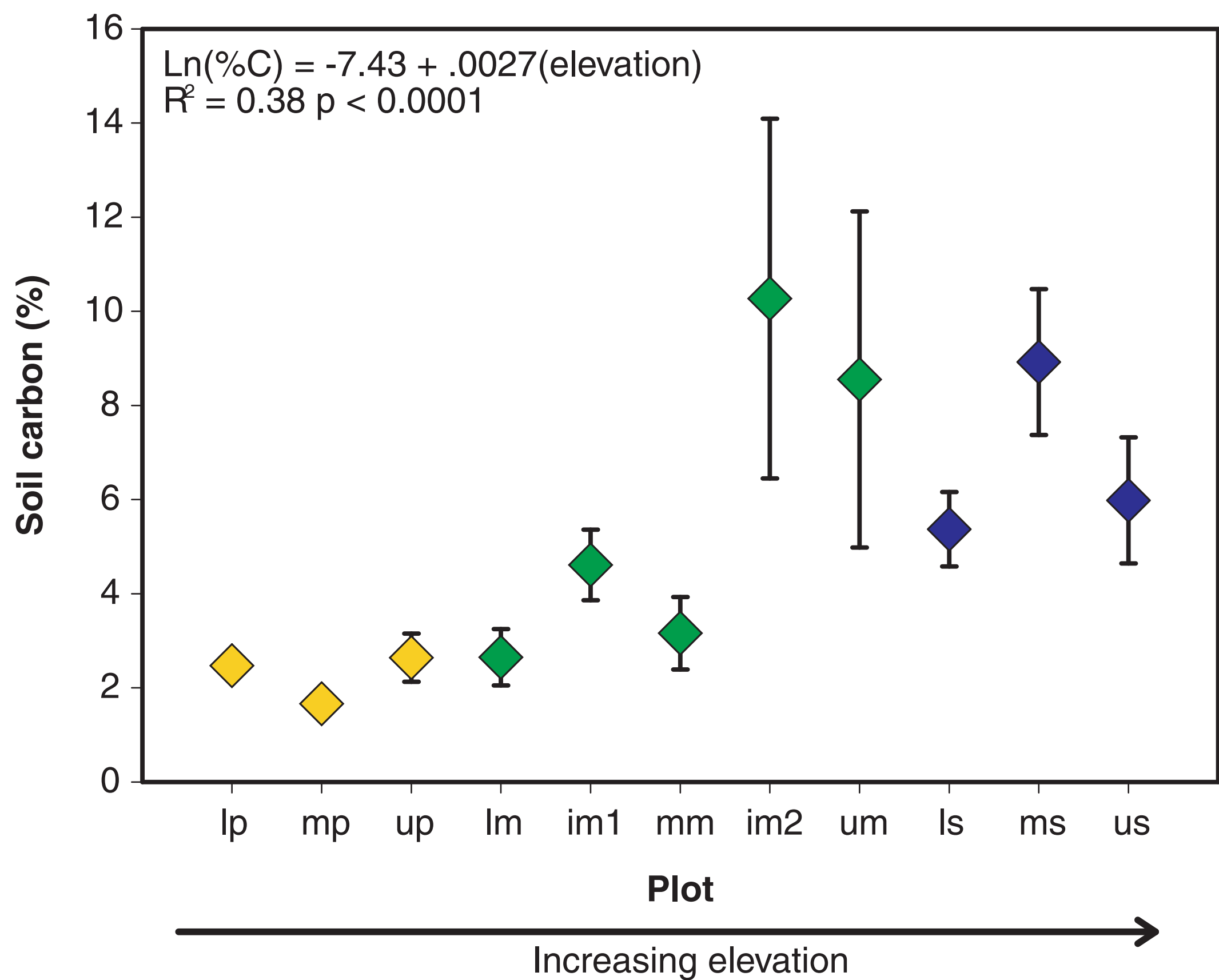


Spruce-fir and pine forest line the Crystal Creek watershed of Fossil Ridge Wilderness near Gunnison, Colorado. Engelmann spruce and subalpine fir extend up to treeline, while lodgepole pine carpets lower elevation slopes and ridges. Lodgepole pine extends to higher elevations on south facing slopes, while Engelmann spruce is often found in shaded valleys and creekbeds. All three species co-occur in mid-elevation ecotones.

## Sampling design



**Figure 1.** Carbon concentrations in the top 15cm of soil increase with elevation across forest type boundaries. This indicates that more carbon is stored in higher elevation forests. The controls on storage could be due to the cooler moister climate, to traits of the dominant species at higher elevations, or to a combination of ecological and climate factors. Our research seeks to decipher the relative importance of climate and species traits to ecosystem carbon dynamics in order to help predict the effects of climate change on forest carbon storage.



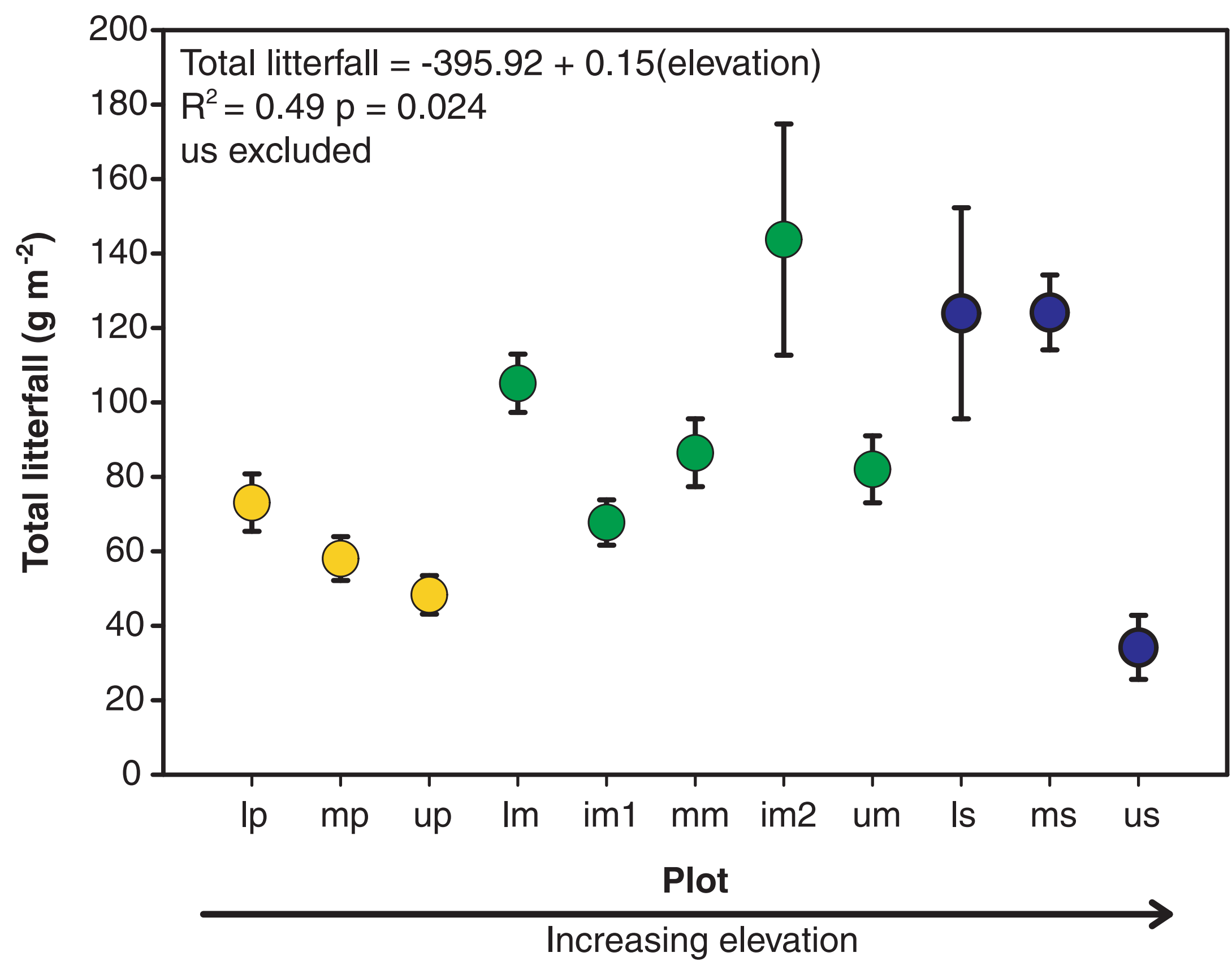
## Abstract

Terrestrial carbon storage is governed by the balance between inputs (net primary production) and outputs (litter decomposition and soil respiration) from ecosystems. Inputs and outputs are controlled both by climate and by the species composition of ecosystems. Currently there is a lack of available data to predict how climate-change-induced species redistribution will alter carbon storage on the landscape. Our preliminary data on ecosystem carbon stocks and fluxes from an elevation and forest type gradient in the Rocky Mountains (see diagram upper left) indicate that soil carbon storage is higher at high elevations and in the presence of Engelmann spruce trees. Lower elevation lodgepole pine forest soil stores much less soil carbon. Differences in productivity along the elevation gradient and between dominant conifer species may be more important than differences in soil respiration or litter decomposition in controlling this pattern. The widespread loss of Engelmann spruce forest and expansion of lodgepole pine forest in the Rocky Mountain west could result in a positive feedback to climate warming through net loss of soil carbon over the long term as well as in a reduction in forest productivity in the shorter term.

## Effects matrix

Soil carbon storage can be affected by Net primary production, Litter decomposition, and Soil respiration (see diagram below right). Each of these processes can in turn be affected by climate variables, such as temperature and moisture, and by species composition. This study seeks to distinguish the relative importance of climate and species to soil carbon dynamics by measuring the relevant stocks and fluxes of carbon in Rocky Mountain conifer forests. Our measurement approaches and results to date are highlighted in the matrix below.

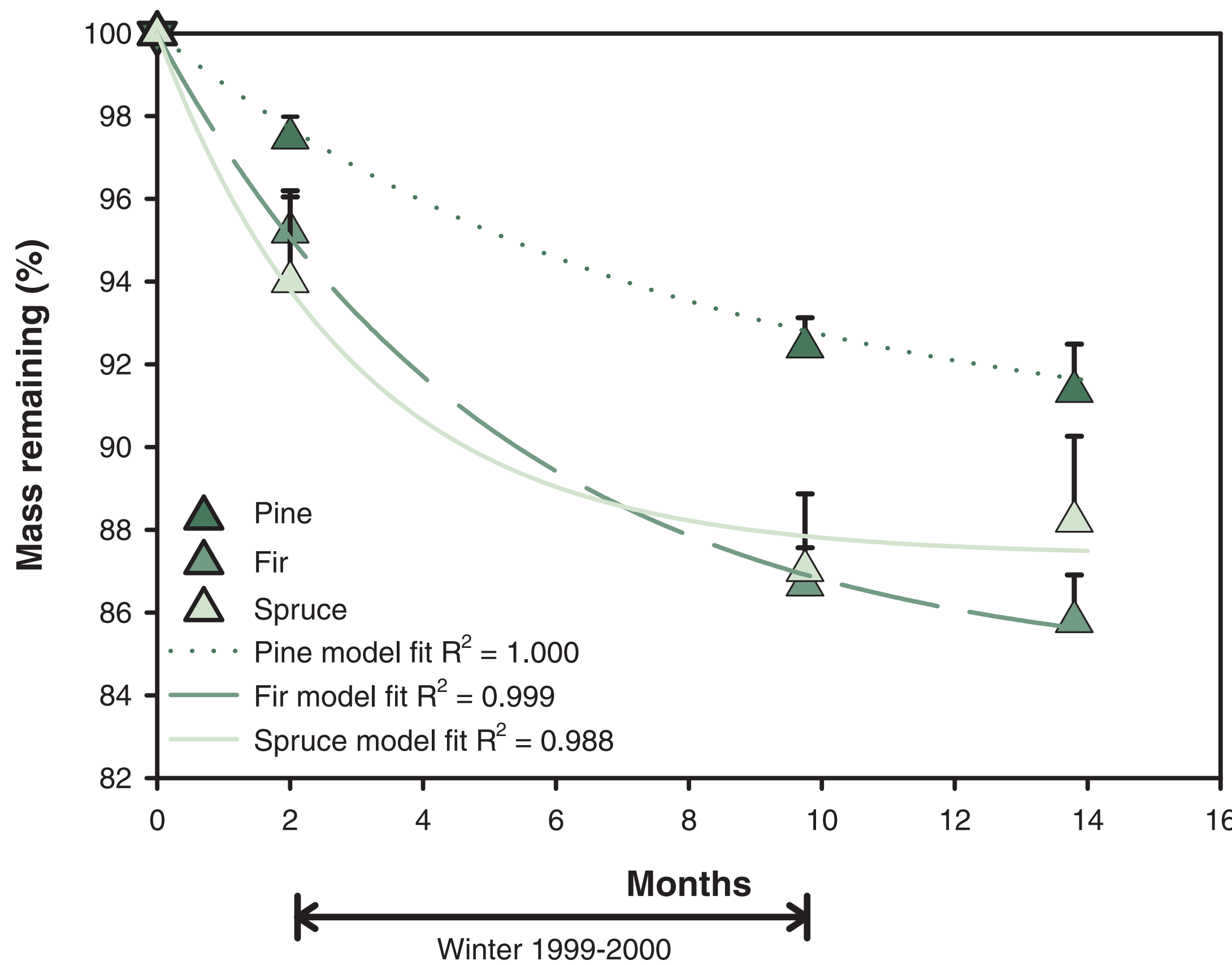
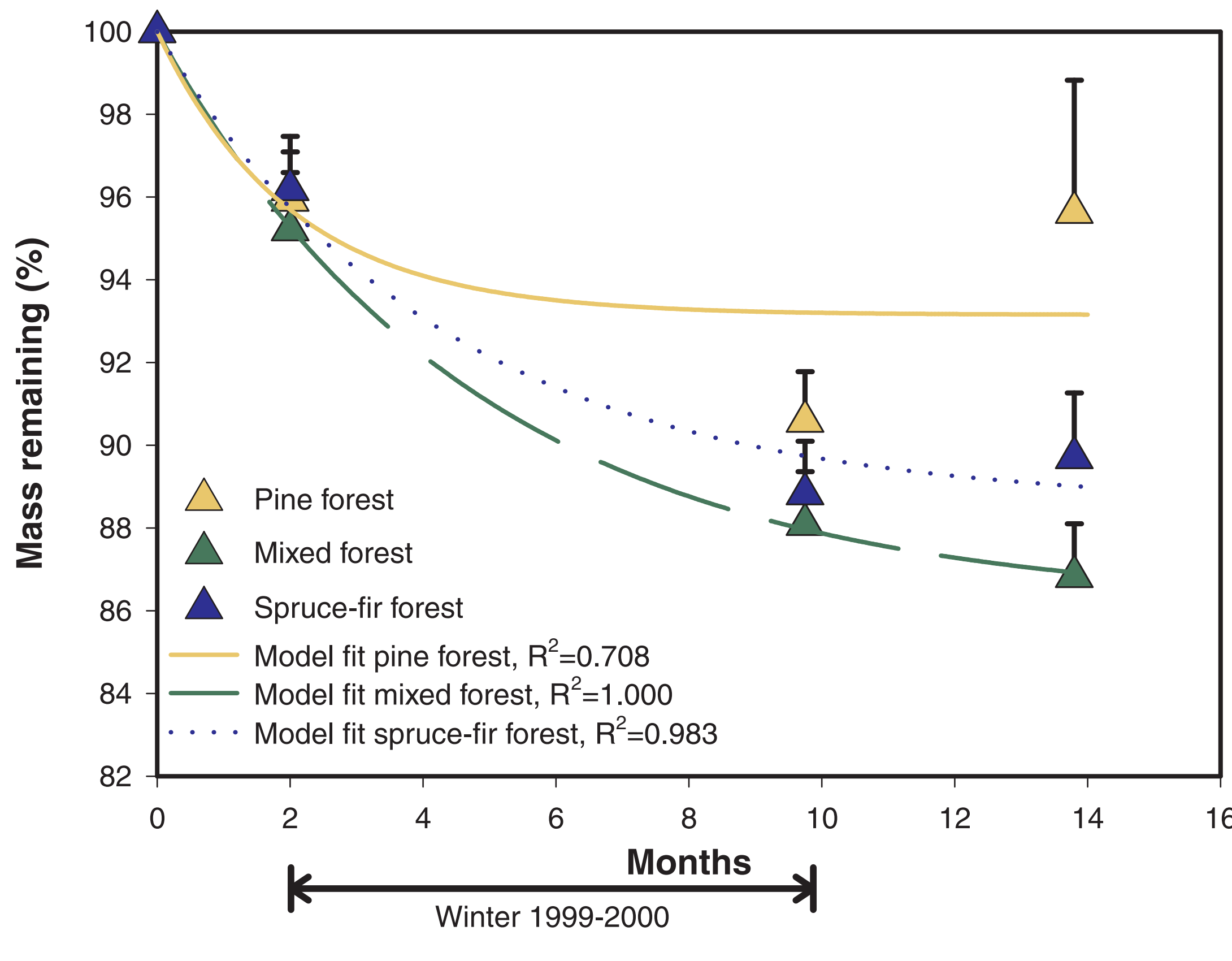
|                | ○<br><i>Litterfall (NPP proxy)</i>  | △<br><i>Litter decomposition</i>   | □<br><i>Soil respiration</i>  |
|----------------|---|--|---|
| <i>Climate</i> | <ul style="list-style-type: none"><li>* Monthly litterfall collection in all sites</li><li>* Total litterfall (over an 11 month period) varies across the elevation gradient, increasing with elevation (Figure 2).</li></ul>     | <ul style="list-style-type: none"><li>* Pine, spruce and fir needle litter in litterbags along the gradient</li><li>* There is a slight difference in % mass remaining at different elevations after 14 months (Figure 3).</li></ul> | <ul style="list-style-type: none"><li>* Soil CO<sub>2</sub> flux measured using soda-lime method</li><li>* There is little difference in soil CO<sub>2</sub> flux along the gradient (Figure 5).</li></ul>                      |
| <i>Species</i> | <ul style="list-style-type: none"><li>* Litterfall is sorted by species so that the relative contribution of each species to litter production can be assessed in the mixed plots where climate is relatively constant.</li></ul> | <ul style="list-style-type: none"><li>* Same method as above</li><li>* There are significant differences in decay rates for each species of needle litter (Figure 4).</li></ul>  | <ul style="list-style-type: none"><li>* Soil will be incubated in the lab at a range of temperatures and moistures to measure differences in climate response functions of soils derived from different forest types.</li></ul> |



**Figure 2.** Litterfall increases with elevation along the gradient suggesting that a cooler moister climate favors net primary production. The highest elevation site (~3590m) does not fit such a model suggesting either that another factor is important at very high elevations or that the response of production to climate may be a hump-shaped curve.

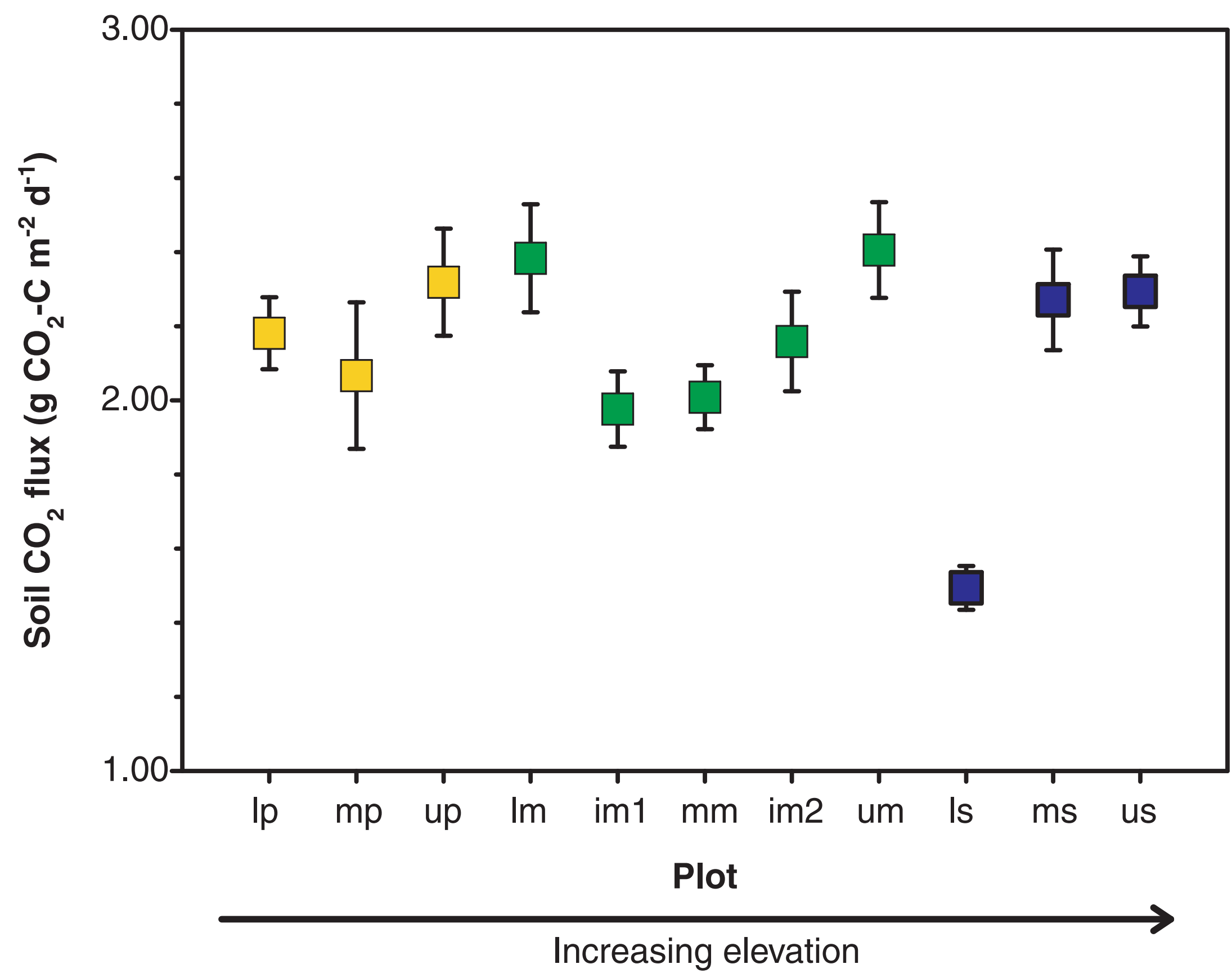


Fungi are largely responsible for litter decay in these conifer forests.



**Figure 3.** Across all species of litter, decomposition was slightly faster in the mixed forest sites than in either the spruce-fir forest or pine forest. The forest type effect (a proxy for elevation and climate) suggests that higher levels of moisture and cooler temperatures favor decomposition. The model used to generate the displayed fits is  $\text{Mass remaining} = a + (100-a) \cdot \exp(-k \cdot \text{Months})$ . For pine forest, mixed forest and spruce-fir forest respectively  $a = 93.15, 86.13$  and  $88.55$ , while  $k = 0.495, 0.208$  and  $0.232$ .

**Figure 5.** During May, June and July, 2000, average soil CO<sub>2</sub> flux did not vary consistently with elevation. The lower spruce site, however, was significantly lower than all other sites at most time points. Further analysis of additional flux measurements and concurrent temperature and moisture data will yield further insight into climate controls on soil CO<sub>2</sub> flux at these sites.



**Figure 4.** Needle litter from pine, spruce and fir trees decomposes at different rates across all sites. The model used to generate the displayed fits is  $\text{Mass remaining} = a + (100-a) \cdot \exp(-k \cdot \text{Months})$ . For pine, spruce and fir respectively  $a = 89.99, 87.38$  and  $84.53$ , while  $k = 0.130, 0.338$  and  $0.192$ .

## Summary and conclusions

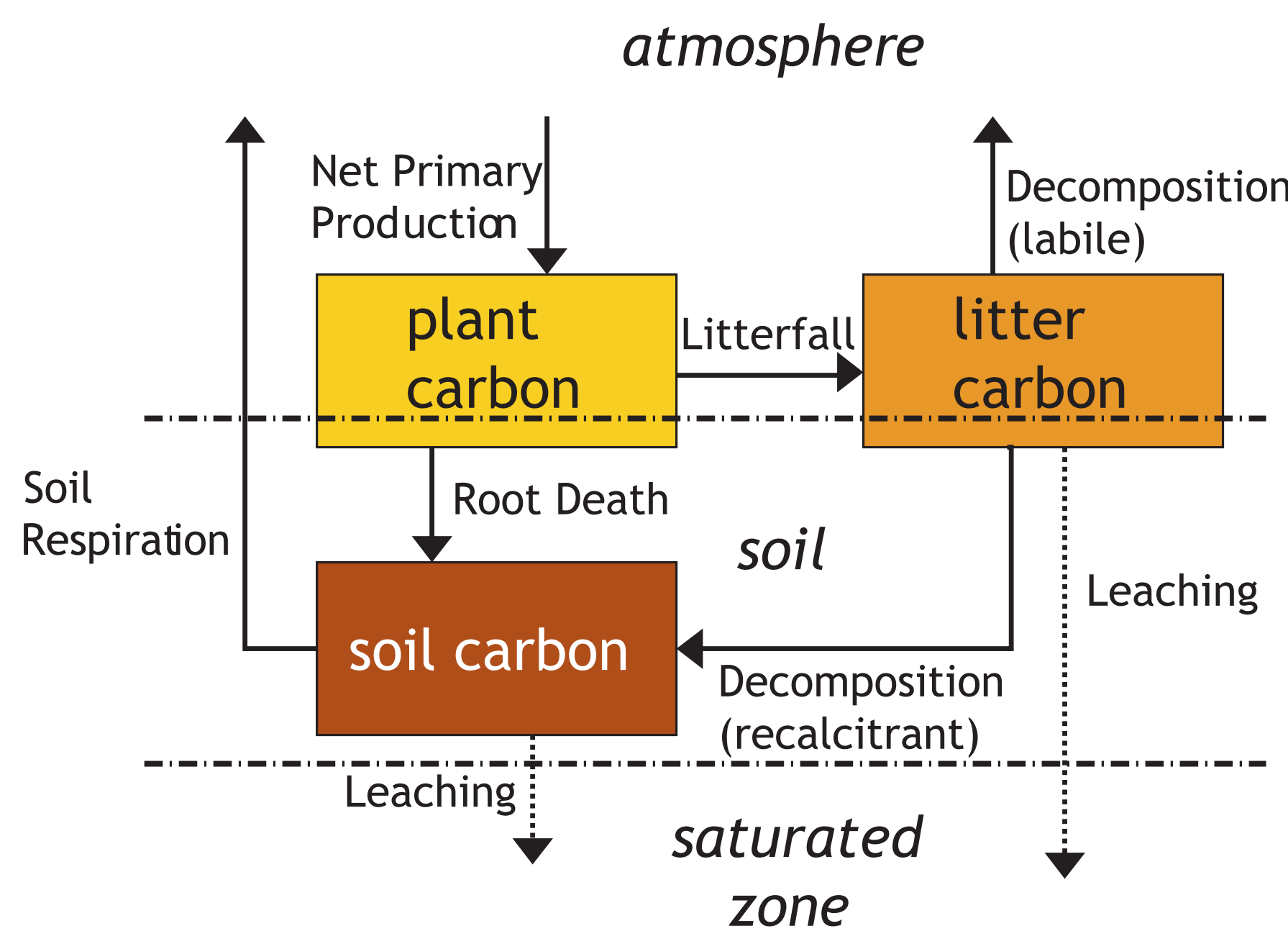
Globally, soil contains more than twice as much carbon as the atmosphere. Both management practices and climate are known to affect the quality and quantity of organic carbon in the soil. Under a changing climate and active human management of landscapes, it is important to understand the ecosystem scale controls on soil carbon dynamics. Under some management and climate conditions soil carbon may be lost to the atmosphere (accelerating global warming) while under others, it may be accumulated (mitigating global warming). A small change in carbon stored in soil could result in a big change in atmospheric CO<sub>2</sub>.

In particular, under a warmer climate, Engelmann spruce- subalpine fir forest in the Rocky Mountain region may become more restricted in its range while lodgepole pine forest expands. This redistribution of forest types together with the direct changes in climate are likely to have a dramatic effect on soil carbon storage throughout the region.

Our preliminary results from a forested elevation gradient in Colorado suggest

- \*Species traits such as litter quality (decomposability) may interact with temperature and moisture regimes to alter the balance of inputs and outputs from soil carbon resulting in a net loss of carbon over the long term,
- \* Levels of plant productivity appear to be more strongly controlled by climate than is soil respiration, and
- \*Soil moisture may be a more important climate control on soil carbon dynamics than temperature in these forests.

## Ecosystem carbon cycle



## Acknowledgements

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